A Study of Various Beacon Antennas for an Orbiting Sample Container of a Future Mars Sample Return Mission

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Abstract — **This paper presents some results of a study of various options for a near-omnidirectional low-gain antenna at UHF frequencies, for a Mars Orbiting Sample Return Container (OS). The OS is part of a concept study for a future mission to return samples from Mars. It would be a critical component of such a mission, which would contain the Mars samples. The notional OS would be returned by a separate spacecraft to Earth. The OS would be identified and located by the spacecraft for pick-up from orbit by a beacon signal broadcast via a surface antenna. Several antenna designs were considered, but two promising ones are presented here which have good patterns with a better than 2:1 VSWR (Voltage Standing Wave Ratio), but meet different criteria for OS design options. One is a patch-type antenna and the other a slot-type antenna. Some data and test results of a fabricated breadboard antenna as well as discussions are provided.**

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1. INTRODUCTION

This work presents the study of the design of a conformal low-gain antenna, which is under development for a Mars Orbiting Sample Canister Beacon, here referred to as OS. It is a part of the most recent effort by JPL's Mars Formulation Office to mature a baseline OS design planned for use on a potential Mars Sample Return (MSR) mission. This spherical canister would be launched from Mars surface filled with samples obtained from Martian soil, and could be in orbit in a random rotation mode, for an approximate duration of 40 sols. It could then be detected by a spacecraft (Sample Return Orbiter or SRO), via reception of its low-bandwidth beacon signal, which would then collect the OS for return to Earth [1].

A preliminary configuration of the OS canister is shown in Figure 1. The space allocated to the antenna is a central ring around the spherical shell.

2. DESCRIPTION AND DESIGN

Two types of antennas are considered: First is a micro-strip patch-type antenna and the second is a slot-type antenna. The selection of antenna is affected by the thermal requirements of OS canister. To maintain an acceptable range of temperature inside the shell, at least 85% of the surface must be covered by gold [1]. This requirement imposes limitations on the design of the conformal antenna. The type of antenna meeting this requirement, as we shall see, is of the slot type and is more complicated to design. However, if this requirement can be relaxed, then the micro-strip patch type of the antenna, which is easier to design, becomes feasible.

Several antenna options were studied. Here, we summarize the design of a patch-type and a slot-type antenna. These results are preliminary and require much further refinements.

The baseline antenna is designed for a narrow band of frequencies centered around 433.5 MHz (Wavelength: 69.156 millimeter or 27.227 inches). It would perform as a quasi-omni-directional antenna with a gain of better than -5 dB for a substantial range of angles, and a VSWR of

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better than 2:1 across the frequency band of interest. The field polarization is linear.

The outer radius of the notional OS shell is about 135 millimeters (5.315 inches), with a circumference of about 848 millimeters or 33.4 inches. Thus, circumference is slightly larger than a wavelength.

Presently, a candidate dielectric material is Torlon 5530 (30% Glass Reinforced PolyAmide-Imide) with a dielectric constant of 6.3.

The "real estate" allocated to the antenna is the central belt of the spherical shell as shown in Figs. 1 and 2. The beacon's signal processing board is inside the shell and is connected to the antenna via a coaxial line.

Patch Antenna

The above dimensional requirements allow for a patch-type antenna on the surface on a dielectric shell of approximately 5 mm in thickness, which can be fed by a coaxial line from inside the spherical shell, having a ground plane on the back of the dielectric shell.

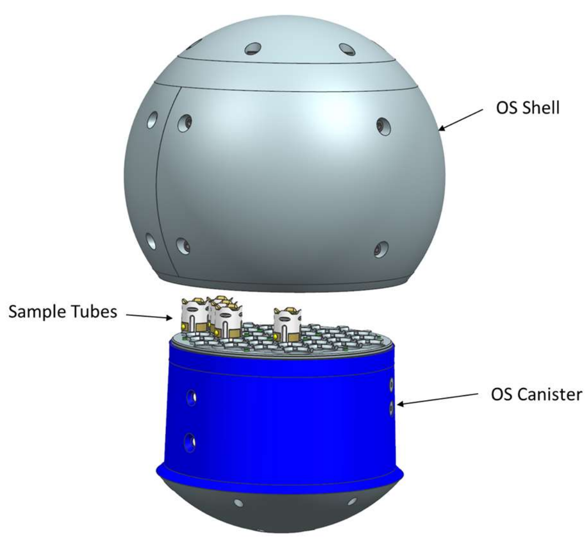

Figure 1. Current OS design concept: exploded view

A number of configuration were studied within the given restraints.

The antenna patch is on the surface of the dielectric, while the ground plane is provided by metallization under the layer of Torlan dielectric. The outer conductor of the coax is connected to the ground plane, while the central line is connected to the surface patch with a circular area used for matching purposes. The shape and dimensions of patch itself were the subject of extensive optimization. Both the HFSS from ANSYS, as well as the CST by DASSAULT SYSTEMS were employed in the design study process.

Two candidate designs presented here. They are shown in figures 2 and 3, with a "bow-tie" configuration. Sample return loss vs frequency and three different views of the pattern are shown in figures 2 and 3.

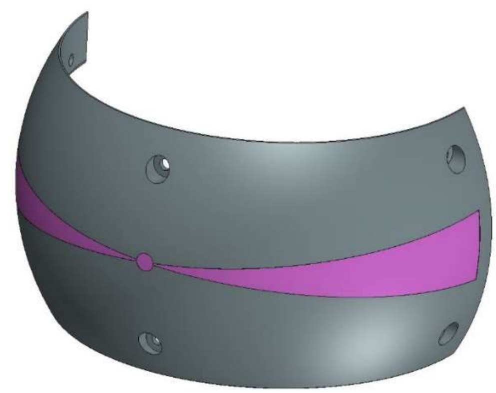

Figure 2. "Bow-tie" patch antenna baseline configuration

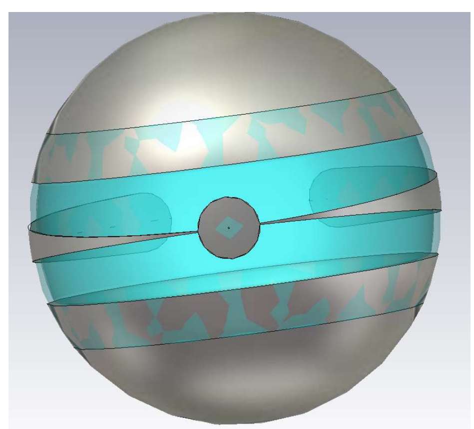

Figure 3. Modified "Bow-tie" patch antenna baseline configuration

These designs are preliminary and subject to further change and improvement.

The study results for Figure 2 design are shown in Figures 4 and 5.

As is observed, the patch-type antennas require a relatively large dielectric area around the patch, which led to our consideration of a slot antenna

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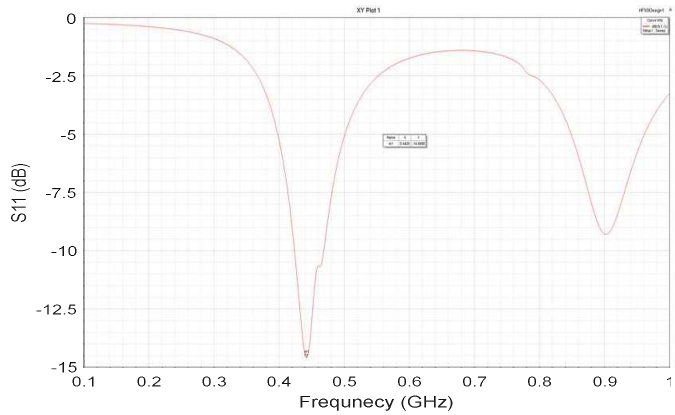

Figure 4. Computed Return loss of the “Bow-Tie” Antenna

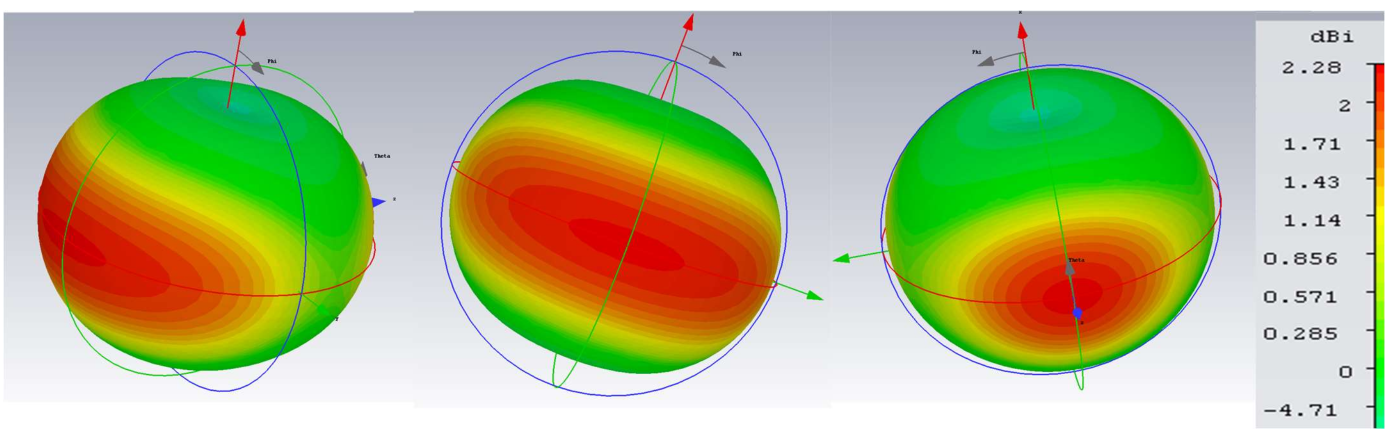

Figure 5. Color-contour antenna directivity pattern viewed from three different directions

Slot Antenna

In order to meet the notional thermal requirements of the OS, which requires a smaller dielectric surface, preliminary studies have been performed on the design of a slot antenna.

The microstrip patch “Bowtie” design required a large dielectric (non-metallic) exposed area of ~ 30% of surface area. Our objective is the design of a slot antenna with less than 5% non-metallic surface areas.

Several configurations were studied using HFSS, based on References [2-5]. Some results are shown in the following figures.

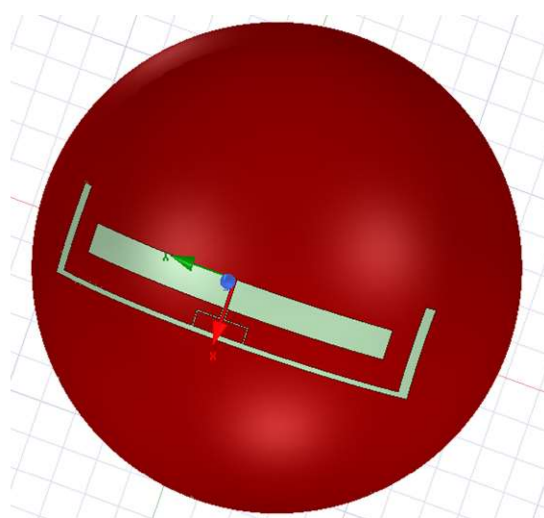

Figure 6. Slot antenna with the matching network

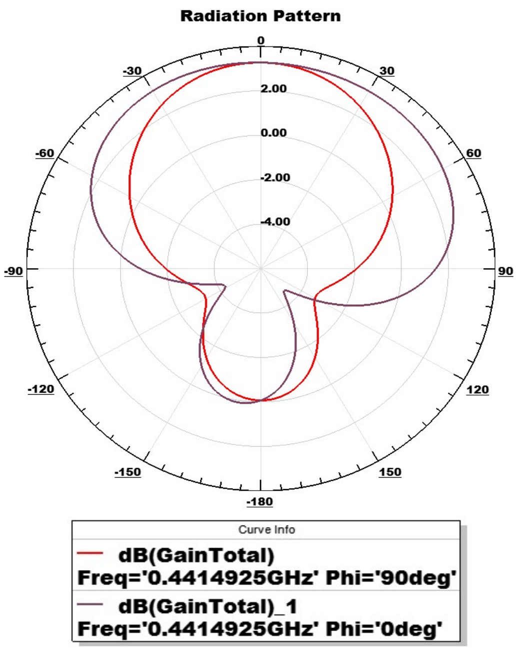

Figure 7. Slot Gain Patterns in two normal cuts

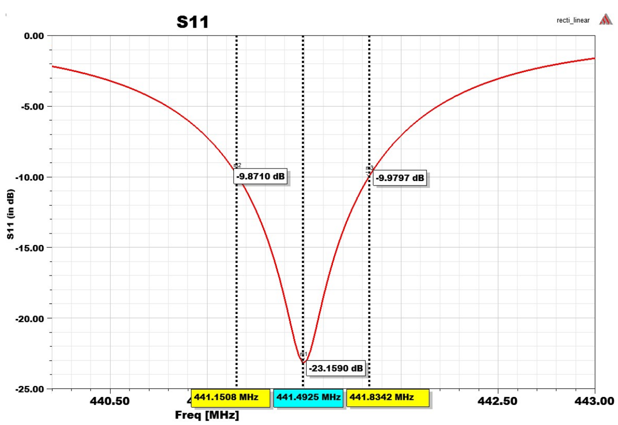

Figure 8. Plot of the VSWR versus frequency

3. Measurements

A patch antenna based on a sample design based on Figure 3 was fabricated and its patterns were measured on the antenna range. The measurement at UHF frequencies were typically difficult to obtain and care must be taken to minimize extraneous radiation. The obtained results are within acceptable range. These results will be presented in a future paper.

4. Summary and Conclusions

A number of antenna configuration were studied within the given space constraints and the requirement to minimized non-metallic exposure to surrounding space. We have successfully designed two types of antennas for this application. One is of the microstrip patch "Bow Tie" and the other is a slot antenna. A sample patch antenna was fabricated and tested with good results.

Additional future work will include the refinement of the slot antenna design together with an appropriate feeding mechanism that fits comfortably within the confines of the OS canister, as well as the physical design of an actual test antenna and the corresponding pattern measurements to verify the design.

Acknowledgements

The help and guidance of Dr. Eric Archer, Mr. David Rosing, and Mr. Tomas Komarek of JPL is gratefully acknowledged. The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

The information about Mars sample return in this paper is pre-decisional and is presented for planning and discussion purposes only.

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BIOGRAPHIES

Hung-Sheng Lin *is an RF Engineer at the Jet Propulsion Laboratory, California Institute of Technology. He received his M.S. and Ph.D. from the Polytechnic Institution of New York University specializing in photonics and electromagnetics. After joining JPL, he has been engaged in research and hardware development in various areas of microwave technology and communication systems. In his early career at defense industry, he was involved in the study, design, measurement and development of microwave components, antenna system from L band to G bands for military applications. His latest work on communication systems involved the development of high power components for X band 80KW CW system. In the past few years, he has been active in development in parallel active and passive microwave subsystem as well as in developing array antennas for digital beam forming for NASA Deep Space Network (DSN).*

Prya Darshni *is a graduate student at the University of Texas, El Paso who interned at JPL during the summer of 2017 and contributed to the design of the slot antenna. Previously, she has done innovative research in transmission line analysis of metamaterials. She has worked on the design and optimization of 2D and 3D filters using genetic algorithm and analysis of spatially variant anisotropic materials using FEM. While studying in IIT-Bombay, she developed a suite of original MATLAB codes on FEM, MoM, FDM and FDTD. She is a member of IEEE.*

Vahraz Jamnejad *is a principal scientist at the Jet Propulsion Laboratory, California Institute of Technology. He received his M.S. and Ph.D. in electrical engineering from the University of Illinois at Urbana-Champaign, specializing in electromagnetics and antennas. Over the years, he has received many US patents and NASA certificates of recognition. He is a senior member of IEEE.*